

Production and interaction of the η meson with nucleons and nuclei

Wojciech Krzemień^{1,*}, Oleksandr Khreptak², Paweł Moskal², Iryna Ozyrianska-Schätti², Oleksandr Rundel², Magdalena Skurzok², and Marcin Zieliński²
for the WASA-at-COSY Collaboration

¹National Centre for Nuclear Research, 05-400 Otwock, Świerk, Poland

²Faculty of Physics, Astronomy and Computer Science, Jagiellonian University, 30-348 Cracow, Poland

Abstract. We report on the status of the search for η -mesic nuclei and the studies of the interaction of the η meson with nucleons. Recently we have completed the analysis of the new WASA-at-COSY data on the production of the η meson with polarized proton beam. New results on the analyzing power for the $\bar{p}p \rightarrow pp\eta$ reaction with more than an order of magnitude improved precision shed a new light on the production mechanism of the η meson in nucleon-nucleon collisions. Also, the latest results of the search for η -mesic nuclei are discussed.

1 Introduction

The η particle together with isoscalar η' and isovector π^0 lay in the origin ($S = 0$, $I_3 = 0$) of the nonet of pseudoscalar mesons representation. However, its behaviour is very different with respect to its interaction with nucleons [1]. In the low energy region, the η meson interaction with nucleons is dominated by the S_{11} resonance, which with its mass of 1535 MeV lays very close to the η -N threshold. This makes the s-wave η -N interaction very strong and - as shown the analysis of Bhalerao and Liu - attractive [2]. This can be contrasted with the pion case which, dominated by the p-wave interaction from the $\Delta(1232)$ resonance, is much weaker [3]. Also, the measurement of the η' -N scattering length shows that its interaction is rather weak [4]. The large value of the η -N scattering length led to the hypothesis, proposed by the Haider and Liu, who postulated that the total interaction in a nucleus- system is strong enough to form a bound-state - the so called mesic nuclei [5]. The second question raised and not unequivocally answered by the earlier measurements was about the η production mechanism in the nucleon-nucleon collisions.

Due to the short lifetime of the meson ($t \approx 10^{-18}$ s) it is not feasible to create the η beam. Therefore, its interaction with nucleon or nuclei must be studied via the observation of final states of nuclear reactions including the η -nucleon (or η -nuclei) pair. The Final State Interaction between produced particles can strongly influence the production cross-sections and, in this way, can be used for studies of the interaction itself [6].

*e-mail: wojciech.krzemien@ncbj.gov.pl

In this contribution we discuss the η production mechanism in the interaction with nucleons and the search for the η -mesic nuclei in the context of the recent experimental results from WASA-at-COSY collaboration.

2 η production mechanism in the interaction with nucleons

The measurements of the large total cross-section of $NN \rightarrow NN\eta$ reaction near the η production threshold [7–18] motivated the two-step η production model proposed in [19]. In this scenario one of the proton is firstly excited through the exchange of a single meson and forms the S_{11} resonance, which in the second step deexcites via the emission of η and nucleon. In principle, the excitation to S_{11} state can occur by exchanging π , η , ω or/and ρ mesons. The measurements of total cross-section isospin dependence by WASA/PROMICE and COSY-11 showed that the η production in the total isosinglet state is much higher than in the isotriplet state [18, 20]. This result strongly suggests the isovector meson exchange, reducing the candidates to π and ρ particles [19, 21, 22]. To further distinguish between the π and ρ meson exchange models, the determination of the analysing power in the polarization measurement was required. The first measurement by COSY-11 gave an indication in favour of the pseudoscalar exchange model, although due to the limited statistics the decisive conclusions could not be done [23–25]. The WASA-at-COSY performed a high-statistics measurement of the $\vec{p}p \rightarrow pp\eta$ with the polarized beam. The spin of the polarization was flipped from cycle to cycle. The data was gathered for two separated beam momenta 2026 MeV/c and 2188 MeV/c, which correspond to excess energy over the η production threshold of 15 MeV and 72 MeV, respectively. More details of the analysis can be found in [26].

3 Search for the η -mesic nuclei

The recent reviews on the search for mesic nuclei can be found in [3, 27–33]. The WASA-at-COSY collaboration [34] performed three dedicated experiments with aim to search for the η -mesic nuclei in ^4He and ^3He systems in the deuteron-deuteron and proton-deuteron collisions, respectively [35–39]. The choice of the light nuclei was motivated by both theoretical considerations (see e.g. [40, 41]) as well as the earlier measurements by SATURNE, ANKE and COSY-11 [42–46], that provided strong experimental hints for the existence of the bound state in the $^3\text{He} - \eta$ and $^4\text{He} - \eta$ systems. The main experimental idea for the ^4He is based on the measurement of the excitation function of the $dd \rightarrow ^3\text{He}N\pi$ reaction for energies in the vicinity of the η production threshold and on the selection of events with low ^3He center-of-mass (CM) momenta. In the case of existence of the $^4\text{He} - \eta$ bound state we expect to observe a resonance-like structure in the excitation function below the threshold for the production of the $^4\text{He} - \eta$ system. The ^3He state is investigated in proton on deuteron collisions. The details can be found in [47].

4 Summary

The latest preliminary results from the 2010 experiment in $^4\text{He} - \eta$ system, do not confirm the existence of the η -mesic nuclei. The preliminary value of the upper limit obtained from the simultaneous fit, taking into account the isospin dependence of the $dd \rightarrow (^4\text{He} - \eta)_{\text{bound}} \rightarrow ^3\text{He}n\pi^0$ and $dd \rightarrow (^4\text{He} - \eta)_{\text{bound}} \rightarrow ^3\text{He}p\pi^-$ excitation functions, of order of few nb can be compared to the theoretical estimate of 4 nb [48]. In case of the $^3\text{He} - \eta$ system, the analysis is ongoing. The current experimental upper limit for the production of $pd \rightarrow (^3\text{He} - \eta)_{\text{bound}} \rightarrow ppp\pi^-$ comes from the COSY-11 measurement and is equal to about 270 nb [49]. Due to the high statistics the expected sensitivity in current WASA

analysis is of order of 10 nb, which, taking into account the theoretical estimate of 80 nb [50], should be sufficient to confirm or rule out the hypothesis of existence of the $^3\text{He} - \eta$ mesic nuclei.

The WASA-at-COSY determined the analysing power in the $\vec{p}p \rightarrow pp\eta$ reaction with two order of magnitude higher precision than the previous COSY-11 measurement. The preliminary results of the angular dependency of the analysing power is in disagreement with the prediction by both the pseudo-scalar and the vector exchange models. For higher energy ($Q = 72$ MeV), the Ps-Pp interference is clearly observed.

We acknowledge support by the Polish National Science Center through grant No. 2011/03/B/ST2/01847, 2011/01/B/ST2/00431, 2013/11/N/ST2/04152, by the FFE grants of the Research Center Juelich, by the EU Integrated Infrastructure Initiative HadronPhysics Project under contract number RII3-CT-2004-506078 and by the European Commission under the 7th Framework Programme through the Research Infrastructures action of the Capacities Programme, Call: FP7- INFRASTRUCTURES-2008-1, Grant Agreement N. 227431.

References

- [1] P. Moskal *et al.*, Phys. Lett. B **482**, 356 (2000)
- [2] R. S. Bhalerao and L. C. Liu, Phys. Rev. Lett. **54**, 865 (1985)
- [3] B. Krusche and C. Wilkin, Prog. Part. Nucl. Phys. **80**, 43 (2014)
- [4] E. Czerwiński *et al.*, Phys. Rev. Lett. **113**, 062004 (2014)
- [5] Q. Haider and L. C. Liu, Phys. Lett. B **172**, 257 (1986)
- [6] P. Moskal *et al.*, Prog. Part. Nucl. Phys. **49**, 1 (2002)
- [7] E. Chiavassa *et al.*, Phys. Lett. B **322**, 270 (1994)
- [8] H. Calén *et al.*, Phys. Lett. B **366**, 39 (1996)
- [9] H. Calén *et al.*, Phys. Rev. Lett. **79**, 2642 (1997)
- [10] F. Hibou *et al.*, Phys. Lett. B **438**, 41 (1998)
- [11] J. Smyrski *et al.*, Phys. Lett. B **474**, 182 (2000)
- [12] A M. Bergdolt *et al.*, Phys. Rev. D **48**, 2969 (1993)
- [13] M. Abdel-Bary *et al.*, Eur. Phys. J. A **16**, 127 (2003)
- [14] P. Moskal *et al.*, Phys. Rev. C **69**, 025203 (2004)
- [15] P. Moskal *et al.*, Eur. Phys. J. A **43**, 131 (2010)
- [16] H. Petren *et al.*, Phys. Rev. C **82**, 055206 (2010)
- [17] H. Calén *et al.*, Phys. Rev. C **58**, 2667 (1998)
- [18] P. Moskal *et al.*, Phys. Rev. C **79**, 015208 (2009)
- [19] G. Fäldt and C. Wilkin, Phys. Scripta **64**, 427 (2001)
- [20] H. Calén *et al.*, Phys. Rev. C **58**, 2667 (1998)
- [21] K. Nakayama *et al.*, Phys. Rev. C **68**, 045201 (2003)
- [22] K. Nakayama *et al.*, Phys. Rev. C **65**, 045210 (2002)
- [23] P. Winter *et al.*, Eur. Phys. J. A **18**, 355 (2003)
- [24] P. Winter *et al.*, Phys. Lett. B **544**, 251 (2002)
- [25] R. Czyzykiewicz *et al.*, Phys. Rev. Lett. **98**, 122003 (2007)
- [26] I. Ozerianska-Schatti arXiv:1607.07261 (2016)
- [27] A. Gal *et al.*, Acta Phys. Polon. B **45**, 673 (2014)
- [28] H. Machner, J. Phys. G **42**, 043001 (2015)
- [29] C. Wilkin, Acta Phys. Polon. B **47**, 249 (2016)

- [30] N. G. Kelkar *et al.*, Rept. Prog. Phys. **76**, 066301 (2013); Acta Phys. Polon. B **46**, 113 (2015)
- [31] S. Bass *et al.*, Acta Phys. Polon. B **47**, 373 (2016)
- [32] Q. Haider, L. C. Liu, Int. J. Mod. Phys. E **24**, 1530009 (2015)
- [33] P. Moskal, Few Body Syst. **55**, 667 (2014); Acta Phys. Polon. B **47**, 97 (2016)
- [34] WASA-at-COSY Collaboration: H. -H. Adam *et al.*, arXiv:nucl-ex/0411038 (2004)
- [35] P. Adlarson *et al.*, Phys. Rev. C **87**, 035204 (2013)
- [36] W. Krzemien, P. Moskal, M. Skurzok, Acta Phys. Polon. B **45**, 689 (2014)
- [37] M. Skurzok, W. Krzemień, O. Rundel and P. Moskal, Acta. Phys. Polon. B **47**, 503 (2016)
- [38] W. Krzemień, arXiv:1202:5794, Ph.D. thesis, Jagiellonian University (2011)
- [39] M. Skurzok, arXiv:1509:01385, Ph.D. thesis, Jagiellonian University (2015)
- [40] S. Wycech, A. M. Green, J. A. Niskanen, Phys. Rev. C **52**, 544 (1995)
- [41] C. Wilkin, Phys. Rev. C **47**, 938 (1993)
- [42] N. Willis *et al.*, Phys.Lett. B **406**, 14 (1997)
- [43] P. Moskal, J. Smyrski, Acta. Phys. Pol. B **41**, 2281 (2010)
- [44] J. Smyrski *et al.*, Phys. Lett. B **649**, 258 (2007)
- [45] T. Mersmann *et al.*, Phys. Rev. Lett. **98**, 242301 (2007)
- [46] W. Krzemien *et al.*, Int. J. Mod. Phys. A **24**, 576 (2009)
- [47] O. Rundel *et al.* these proceedings, (2016)
- [48] S. Wycech, W. Krzemien, Acta Phys. Polon. B **45**, 745 (2014)
- [49] P. Moskal, J. Smyrski, Acta Phys. Polon. B **41**, 2281 (2010)
- [50] C. Wilkin, Acta Phys. Polon. B **45**, 603 (2014)